KREEP IN THE WESTERN LUNAR HIGHLANDS: AN ION MICROPROBE STUDY OF ALKALI AND MG SUITE CUMULATES FROM THE APOLLO 12 AND 14 SITES.

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Introduction: Cumulate plutonic rocks of the Western Lunar Highlands Province [1] are chemically and petrologically distinct from the more common ferroan anorthosites found elsewhere, reflecting their origin from magma series which post-date the lunar magma ocean. Deciphering the origin and evolution of plutonic rocks in the western lunar highlands is difficult because of the small size of the highland rock clasts recovered from breccias [e.g., 2], and because it is impossible to calculate parent magma compositions from whole rock chemical data on cumulate rocks.

We report here results from our continuing effort to characterize the parent magmas of alkali suite and Mg-rich suite lunar cumulates by using the ion microprobe and electron microprobe to analyze their cumulus phases [3, 4]. Parent magma compositions are calculated from the phase chemistry using equilibrium crystal/liquid partition coefficients. This approach eliminates the need for "representative" bulk rock samples, and it allows us to evaluate the evolution of the trapped intercumulus melt during closed system crystallization.

Results: Nineteen samples have been analyzed so far, including nine Mg-rich samples, eight alkali suite, and two probable mare cumulates (Table 1). All but four of these samples were analyzed with the MIT-WHOI Cameca 3f SIMS ion microprobe; the other four samples were analyzed with the UNM-SNL Cameca 4f SIMS ion microprobe. Two to eleven spots were analyzed on each sample for 8 rare earth elements. In most cases, the cores of large relict cumulus grains were analyzed. Several samples, however, were probed in more detail to check for zoning in the relict cumulus grains and to compare the relict cumulus grains to polygonal recrystallized grains. Post-cumulus pyroxenes were analyzed in several samples to trace the evolution of the trapped liquid, and to check for post-cumulus re-equilibration. Transition element and LILE analyses are in progress.

Table 1. Samples analyzed by SIMS for trace element concentrations in pyroxene and or plagioclase.

Generic	Specific	Parent or WRx ##	Suite	Rock Type	Pristine Index*	SIMS Analy	Prime Refer.
12033	,575	,425	Alkali	Anorthosite	8.0	4	[5]
12073	,118	,122	Alkali	Anorthosite	6.6	4	[6]
14047	,142	,113	Alkali	Anorthosite	6.9	8	[7]
14160	,108	,106	Alkali	Anorthosite	6.5	6	[8]
14304	,279	,87 g	Alkali	Norite	7.0	9	[9]
14305	,303	,283	Alkali	Anorthosite	6.8	2	[7]
14305	,412	,400	Alkali	Anorthosite	6.2	11	[11]
14318	,177	,149	Alkali	Norite	6.0	7	[7]
14304	,251	,109 q	Mg-rich	Troctolite	6.0	4	[9]
14305	,301	,279	Mg-rich	Cpx Troctolite	8.0	3	[7]
14305	,320 W7	,322	Mg-rich	Anorthosite	6.6	2	[11]
14305	,347 W6	,317	Mg-rich	Opx Troctolite	6.6	4	[11]
14305	,394 W1	pr.mount	Mg-rich	Troctolite	7.2	5	[11]
14305	,405	,389	Mg-rich	Opxite	7.3	4	[11]
14321	,1235	,1140	Mg-rich	Troctolite	6.3	5	[12]
14321	,1241	,1154	Mg-rich	Troctolite	7.4	3	[12]
14321	,1273	,1211	Mg-rich	Anorthosite	5.6	8	[12]
14318	,4	pr.mount	Mare?	Gabbronorite	n.r.	2	[10]
14305	,102	pr.mount	Mare?	Gabbronorite	n.r.	5	[10]

Melts in equilibrium with phases analyzed were calculated using experimental and empirical partition coefficients for pyroxene and plagioclase [15-16]. Samples that were analyzed in detail display compositional zoning in primary cumulus grains that can be attributed to normal igneous zoning. Whitlockite-bearing Mg anorthosite 14321 ,1273 shows a progressive enrichment in REE from core to rim (La= 18x to 25x chondrite) in a large cumulus plagioclase with relict twinning, while polygonal recrystallized plagioclase is similar to the cumulus core in composition (La=20x chondrite). Post-cumulus, interstitial clino-pyroxene shows large variations in composition, with La ranging from 25x chondrite to

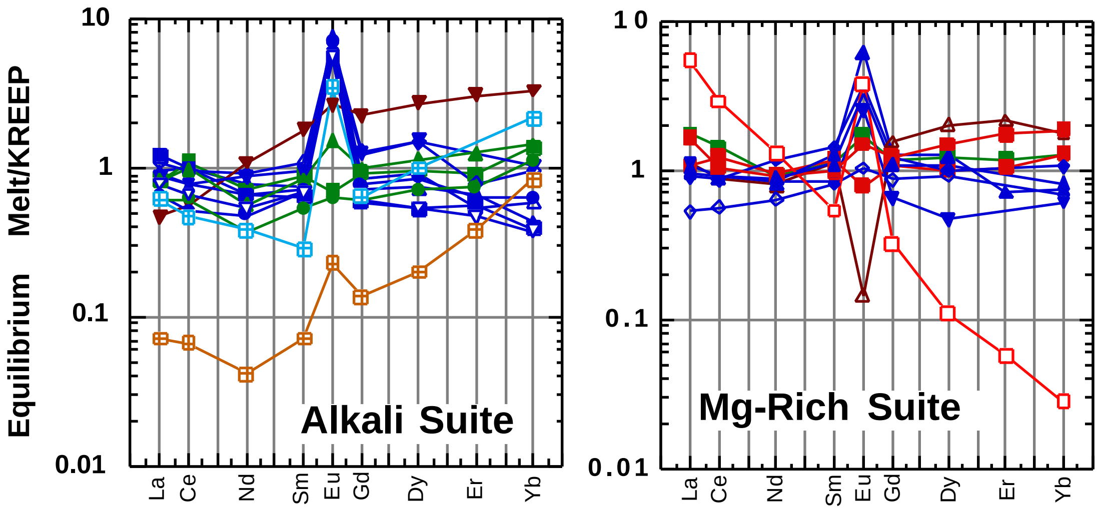

Figure 1. Calculated equilibrium parent magmas for plagioclase and pyroxene, normalized to high-K KREEP of Warren [17].

98x chondrite; the highest values are found in a small grain adjacent to whitlockite. Overall, these results suggest that primary magma-crystal partitioning relations are preserved in these samples, and that equilibrium crystal/liquid partition coefficients can be used with carefully chosen cumulus core compositions to calculate the trace element composition of the parent magmas.

Parent magmas calculated for the samples studied thus far are shown above, normalized to the high-K KREEP component of Warren [17]. Almost all samples from both suites are characterized by calculated parent magmas with REE-patterns similar to high-K KREEP, despite the wide range in major element compositions of the phases (olivine Fo89 to Fo84, Opx Mg# 91 to 65, plagioclase An95 to An78). This implies that the parent magmas of both suites contain large amounts of admixed KREEP component, or alternately, the alkali suite may represent KREEP parent magma [e.g., 1, 18]. The Mg-rich suite parent magma may represent more primitive magma that mixed with an urKREEP component to form "pristine KREEP", as suggested by Warren [19]. These results are consistent with the hypotheses of Warren that most Mg-suite parent magmas assimilated at least some KREEP prior to crystalliztion, and were enriched in plagiophile elements (like Eu) by plagioclase dissolution [20]. Similar results have been reported by Papike et al [21, 22] for Mg suite norites. Note that one difference between these suites is the position of the calculated Eu anomaly, which is about 3x KREEP in the Mg-rich suite, but is 5x to 6x KREEP in the alkali suite. This same effect is observed in the whole rock data [1, 18].

Conclusions: The data presented here show that ion microprobe analyses of primary cumulus phases in lunar highland cumulates can be used to determine the composition and petrologic history of their parent magmas independently of bulk rock compositional data. These data also show that parent magmas of both the Mg-rich suite and the alkali suite have strong affinites with KREEP, and may even represent cumulates from pristine KREEP magmas. Transition element and LILE data are being collected to decipher these alternatives.

References: [1] Shervais, 1991, LPI-Tech. Report 89-03, 82-91; [2] Shervais et al, 1990, Proc. 20th LPSC, v20, 109-126; [3] Shervais, 1994, LPSC XXV, 1265-1266; [4] Shervais & Stuart, 1995, LPSC XXVI, 1285-1286; [5] Warren et al, 1990, Proc. 20th LPSC, 31-59; [6] Warren et al, 1981, Proc. LPSC 12th, 21-40; [7] Warren et al, 1983, Proc. 14th LPSC, JGR Supl. v88, A615-A630; [8] Warren & Wasson, 1980, Proc. Conf. Lunar Highlands Crust, 81-99; [9] Goodrich et al, 1986, Proc. 16th LPSC, JGR v91, D305-D318; [10] Shervais et al, 1983, Proc. 14th LPSC, JGR Supl. v88, B177-B192; [11] Shervais et al, 1984, Proc. 15th LPSC, JGR Supl. v89, C25-C40; [12] Lindstrom et al, 1984, Proc. 15th LPSC, JGR Supl. v89, C41-C49; [13] Grutzeck et al, 1974, Geophys. Res. Lett., v1, 273-275; [14] McKay et al, 1991, LPS XXII, 883-884; [15] Phinney & Morrison, 1990, Geochim. Cosm. Acta, v54, 1639-1654; [16] Phinney, 1991, Proc. 21st LPSC, v21, 29-49; [17] Warren, 1991, LPI-Tech. Report 89-03, 149-153; [18] Snyder et al, 1995, GCA, v59, 1185-1203; [19] Warren, 1988, Proc. 18th LPSC, 233-241; [20] Warren, 1986, Proc. 16th LPSC, JGR v91, D331-D343; [21] Papike et al, 1991, Amer. Min, v79, 796-800; [22] Papike et al, 1996, GCA, v60, 3967-3978.